OPTICAL COMMUNICATION TRANSCEIVER FOR X2000; SECOND DELIVERY PROGRAM

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Abstract

Conceptual-design of a multi-functional optical instrument is underway for the X2000 - Second Delivery Program. The transceiver will perform both free-space optical-communication and science imaging by sharing a common 10-cm aperture telescope. A single focal-plane array (such as, APS- Active Pixel Sensor) in conjunction with a filter wheel will be used to perform the two functions. Targeted values for the transceiver's weight and power consumption are: 4 Kg, and 14 W. This transceiver would be capable of delivering greater than 10 Kbps to a 3.5-m diameter receiving station from the range of 2 AU during day-time.

Introduction

Optical communications provides a compact transceiver with potential for light-weight and low power consumption. Moreover, with the addition of a filter-wheel to the transceiver design, it also functions as a high-resolution, multi-color imager. The downlink operation of the transceiver consists of tracking a laser beacon (emanated from earth) or the sun-illuminated earth image beacon, and transmitting a signal back to the ground station.

Requirements

The top level requirements for the transceiver are:

- Multi-functionality: optical communication and at least narrow-angle science imaging
- downlink capability of 10's of kbps and uplink reception capability of 2 kbps from 2 AU
- Acquisition, tracking and reception of uplink command while transmitting a strong downlink signal through the same aperture
- proper pointing of the highly collimated laser beam to earth while the host spacecraft is oscillating, jittering, contracting and expanding. Maintaining pointing of the transmit signal during daytime reception with an absolute accuracy on the order of a few micro-radians.

- Acquisition and tracking of the ground receiver locations, from deep space, for a wide range of Sun-Earth-Probe (SPE) angles.
- Simultaneous two-way ranging and communication support
- Adequate level of built-in reliability to survive the targeted mission period and to remain opto-mechanically and thermo-mechanically stable during launch, cruise and intense operation phases of the mission.

Link Analysis

To minimize size, weight and power consumption, a small transmit/receive aperture along with low average output transmit laser power were assumed. Major assumptions for the link analysis are:

Transmitter/receiver aperture = 10 cm	Link range = 2 AU
Laser transmitter average power = 1 W	Receiver diameter = 3.5 m
Modulation format = 256 (8-bit) PPM	Daytime ground reception
Transmitter pointing losses = - 2 dB	Bit error rate = 1 E-5
Coding = Reed-Solomon	Link Margin = 3 dB

With these and certain assumptions on transmit, receive and atmospheric losses, a date rate of greater than 10 kbps is calculated. Larger ground-based receiver apertures (such as 10-m photon bucket) in conjunction with night-time reception result in a calculated data-rate capability of greater than 140 kbps.

Conceptual Optical Configuration

An optical block diagram for the transceiver is shown in Figure 1.

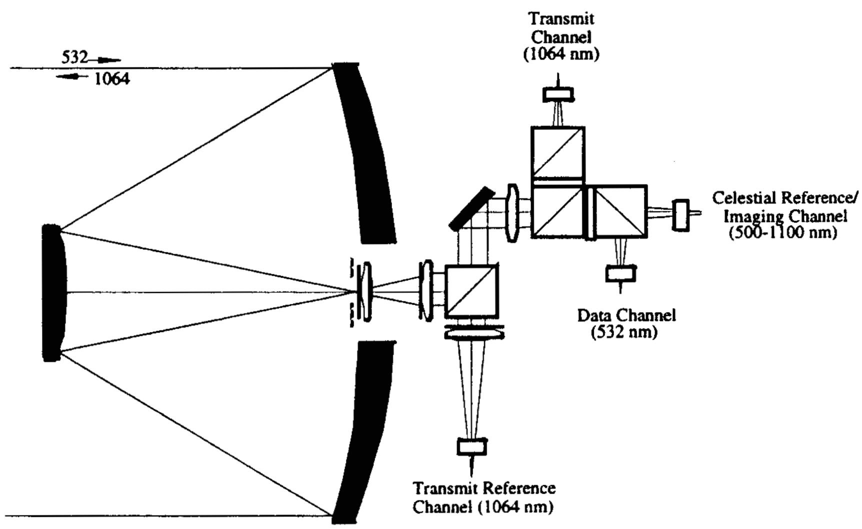

Figure 1. Conceptual Optical Diagram for the Transceiver

The optical system consists of four optical channels.

The transmit channel consists of an optical path to relay a transmit signal from the output of the laser transmitter to the exit aperture of the optics. This channel provides fine-pointing capability to control the downlink over the entire system field-of-view.

The data detector receive channel consists of a receive optical path to collect the incident photons from the input aperture and transfer them to the data detector. This path provides narrow-band filtering to reduce the amount of background radiation, and provides the field-of-view necessary to cover the spacecraft deadband cycle.

The tracking receive channel consists of an optical path that images the telescope field-of-view onto the celestial reference detector. A 1024x1024 detector array with 20 micron pixel size is currently baselined and covers the 9 mrad x 9 mrad field-of-view.

The tracking reference channel consists of a tracking reference path that images a small portion of the transmit signal (after the fine-pointing mirror) onto the tracking detector. The instantaneous direction of the downlink signal is measured in this channel.

The dynamic range of the tracking signal can vary by 2 to 3 orders of magnitude over the large distances expected, and particularly when earth image tracking is required. Current CCD and APS technology do not permit operation over different frame rates for the two signals. Thus, the transceiver is equipped with a separate imager that images the tracking reference signal.

The transmit signal must be pointed ahead (or behind) the apparent position of the ground station to compensate for any cross velocity. The initial acquisition and coarse pointing of the transceiver is achieved using the spacecraft attitude itself. Fine pointing of the transmit signal is achieved using a two-axis steering mirror in the transmit channel. Following sensing of the position of the beacon image on the focal-plane-array detector relative to the reference location for the center of the receive channel, the steering mirror can be used to correct the pointing of the transmit channel towards the ground station.

Weight and power-consumption goals for the transceiver are: 4 kg and 14 W, respectively. The largest dimension is estimated as 25 cm.

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Free-Space Optical Communications Program at JPL

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Future missions will fly smaller spacecraft with instruments that will generate greater data volumes than current spacecraft. To support these missions the telecommunications terminals need to be small, with low mass and power consumption. Lasercomm is seen as the technology that will meet these needs for future near-earth, solar system and interstellar missions. An experimental transmitter that will downlink data at rates greater than 1 Gbps is being constructed. Under its X2000 program, JPL plans to develop a deep space optical communications transceiver for micro-spacecrafts that would, in an early demonstration, support 10's of Kbps data-rate from 2 AU range. Current NASA plans call for building the first of two 10-m-class ground receiving telescopes by year 2008. NASA is currently building a 1-m R&D telescope laboratory at its Table Mountain Facility in southern California to answer key implementation questions of this technology. The telescope is designed with fast tracking capability and will act as a testbed for development of ground acquisition, tracking and communications strategies applicable to future operational stations. These and other programs currently under development are described below.

High Efficiency Component and Subsystem Technology Development: The aim of these efforts are to substantially improve the efficiency and performance of components and subsystems for laser-communication terminals. Mass and the required DC power for the flight instrument are both very expensive commodities, particularly in deep-space missions. Efficiency of high-data-rate (Gbps level) transmitters and low data-rate (kbps level) diode-pumped solid-state lasers are being improved. High bandwidth, low-mass fine-pointing mirrors (both mechanical and non-mechanical) are being evaluated in the acquisition and tracking testbed. Compact, low power consumption (< 0.1 W), large area (1024 x 1024 pixels), high update-rate acquisition and tracking focal-plane arrays (FPAs) including active-pixel-sensors and new generations of CCDs are being developed at JPL and are characterized in the testbed. When the optical communications telescope looks back at earth for acquisition and tracking and downlink, the sun is generally in the background and at times partially within its field-of-view. This causes a number of challenges (such as signal-to-noise deterioration and heating of the telescope) that have to be addressed effectively. For this purpose, low-mass, very low thermal expansion optical systems with very effective background filtering are being investigated.

Acquisition, Tracking and Pointing (ATP) Algorithms and Testbed: ATP is a critical element of optical communication whose implementation strategy is determined primarily by range. Currently concepts that address links up to 0.5 AU have been demonstrated using FPA centroiding accuracy of only $1/10^{th}$ of a pixel, leaving only micro-radians of pointing error. Extended link ranges will require up to five times more centroiding accuracy. The objective of the on-going research effort is to reduce pointing error to the sub-micro-radian level by developing and demonstrating in a simulated space environment, algorithms capable of achieving high-bandwidth, high-accuracy centroiding ($1/50^{th}$ of a pixel). We expect to achieve such an improvement using state-of-the-art FPAs together with innovative ATP concepts which combine extended-source-tracking, sensor feedback, and isolators. To experimentally evaluate these algorithms, an acquisition and tracking testbed was developed where spacecraft vibration, both point-source and extended-source beacon, and background light can be simulated.

Transmitter and Receiver Testbed (for flight and ground): A testbed for extensive characterization of a variety of laser transmitters and receivers is under development. This testbed will serve the needs of various on-going programs and could serve programs external to JPL in the near-future. A goal of this testbed is to identify highest quantum-efficiency and lowest noise avalanche photodiodes for both ground and in space reception of the lasercomm signals.

Optical Communication Demonstrator (OCD): OCD is a laboratory-based lasercomm demonstration terminal designed to validate several key technologies, including beacon acquisition, high bandwidth tracking, precision beam-pointing, and point-ahead compensation functions. The instrument has a 10-cm diameter aperture, uses a CCD array for both spatial acquisition and high bandwidth tracking, and a fiber-coupled laser transmitter.

Near-Earth Laser-Communication Transmitter: The International Space Station (ISS) Engineering Research and Technology Development program (ISSERT), is sponsoring the development of a high data rate (up to 2.5 Gbps) lasercomm transmitter from the LEO range (on board the ISS). The terminal design is based on the OCD instrument. It utilizes an eye-safe transmitter wavelength of 1550 nm (compared with 844 nm for OCD).

Deep-Space Laser-Communication Transceiver: A new program called the Advanced Deep-Space Systems Development Program (a.k.a X2000 Program), has been initiated to develop new cutting-edge technologies for NASA's deep-space missions in an overall flight project environment. The X2000 second delivery is a micro-spacecraft (10 to 50 kg) with limited mass and power availability. The transceiver under investigation for this technology development spacecraft is a multi-functional instrument with capability for high-resolution science imaging and ranging in addition to communication. The current baseline is 10's of kbps data-rate from a range of 2 AU.

Laser-Communication Test and Evaluation Station (LTES): LTES is a high quality optical system that measures the key characteristics of lasercomm terminals operating over the visible and near-earth spectral regions. LTES can accommodate terminal apertures up to 20-cm in diameter. LTES has six optical channels and can measure far-field beam pattern, divergence, data-rates up to 1.4 Gbps and bit-error rates as low as 1e-9. It also measures the output power of the laser-terminal's beacon and communication channels, and the point-ahead angle with a resolution of 1 µad.

Optical Communication Technology Data-base: A data-base of lasercomm components and subsystems has been compiled. It is our goal to update it periodically and to make this database available to the community within a year from now.

Ground Receivers and Ground Reception Technologies: Current NASA plans call for building the first of two 10-m-class ground receiving telescopes by year 2008. NASA is currently building a 1-m R&D telescope laboratory at its Table Mountain Facility in Wrightwood, CA, to answer key implementation questions of this technology. The telescope is designed with fast tracking capability to allow JPL engineers to use corner-cube, and laser bearing satellites as testbeds for developing acquisition tracking and communications strategies applicable to future operational stations. Improved receivers for ground reception, definition of requirements and cost-estimates for larger aperture ($\geq$ 10 m) photon-buckets, schemes for implementing near-earth acquisition and communication with the spacecraft, and recovery from spacecraft emergency scenarios are among the ground reception technologies that are being investigated.